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Incorporating Training Effects in Modeling and Simulation Software

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Abstract

This paper describes a research program that is developing more robust algorithms for The Improved Performance Research Integration Tool (IMPRINT) that better reflect the complexity of the effects of training on human performance. The Air Force Research Laboratory's Warfighter Readiness Research Division is sponsoring a series of empirical studies to assess the effects of various training strategies on skill acquisition and retention in the performance of complex military tasks. New algorithms will be developed and populated based on the results of these studies. Ongoing research efforts are described. The relevance of this research for system designers is discussed.

The Improved Performance Research Integration Tool

The Improved Performance Research Integration Tool (IMPRINT) is a modeling and simulation software package that is used by system designers to evaluate human system integration (HSI) questions throughout the life-cycle of a system. This tool can be used both for the human engineering of a system and for the estimation of certain manpower costs across the system's life cycle. Using task networks, IMPRINT is used to estimate human-system limitations and performance concerns, manpower needs, and task allocation effects on workload and performance. IMPRINT also allows system designers to estimate the performance impacts of temperature variations, vibration, fatigue, and stressors. Use of this tool during development affords the identification of human factors engineering issues, fostering human-centered system design and enhanced human and system performance.

IMPRINT currently addresses two requirements: (1) estimating how human performance impacts system/mission success, and (2) estimating how maintenance personnel's individual and

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14. ABSTRACT

This paper describes a research program that is developing more robust algorithms for The Improved Performance Research Integration Tool (IMPRINT) that better reflect the complexity of the effects of training on human performance. The Air Force Research Laboratory's Warfighter Readiness Research Division is sponsoring a series of empirical studies to assess the effects of various training strategies on skill acquisition and retention in the performance of complex military tasks. New algorithms will be developed and populated based on the results of these studies. Ongoing research efforts are described. The relevance of this research for system designers is discussed.

15. SUBJECT TERMS

Training; Training effects; Modeling and simulation; Software; Improved Performance Research Integration Tool; IMPRINT; Human performance; Training strategies; Skill acquisition; Skill retention;

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team performance over sustained periods can affect mission effectiveness across units and at the force level. Most of the human performance variables embedded in IMPRINT have been developed and validated using empirical research findings. The current IMPRINT training algorithms, however, are based on limited experimental data. The only training-related performance effect available to a modeler is the time period since the last training event (e.g., last week, one month ago, six months ago). Task performance times increase and task accuracy decreases with less frequent training

The primary goal of the IMPRINT Training Algorithm Enhancement (ITAE) Program is to include consideration of training and its impacts, especially since Reserve and Guard units are playing an increasingly important role in integrated combat teams. Three aspects of training need to be considered:

1. Initial training and its impact on increasing performance accuracy and reducing performance time,
2. Knowledge and skill retention over periods of non-use, and
3. Rate of recovery when knowledge and skill is rehearsed, exercised, or re-used.

To achieve this goal, The Air Force Research Laboratory's Warfighter Readiness Research Division is sponsoring a series of empirical studies to assess the effects of various training strategies on skill acquisition and retention in the performance of complex tasks. In a recently completed study, new algorithms were developed to reflect the effects of overtraining on performance (McDermott, et. al., 2007). Other studies, which will be discussed in greater detail in this paper, are currently in progress to investigate additional training effects. Specifically, one study is assessing the performance effects of varying levels of instructor interaction for a set of aviation and sensor manipulation tasks. In another effort, researchers are studying automotive maintenance tasks and the performance effects of using hands-on practice during training. Finally, the efficacy of team training interventions is also under investigation.

Instructional Strategies

Among the many factors impacting overall human performance on complex systems is training effectiveness, which can vary as a function of the strategy employed in training operators, maintainers, and teams. The term "instructional strategy" can encompass a number of attributes associated with a given training approach. The development of effective instruction is driven by one of many underlying instructional theories. For instance, proponents of the constructivist theory of instruction believe that students are highly motivated to learn and, when provided the appropriate resources, students will explore and learn the relevant skills. The primary role of the instructor is to provide a rich learning environment and to serve as a facilitator for the students. Depending upon the theoretical orientation of the instructional designer, a variety of instructional methods and media may be used to facilitate learning. Keeping with our example of constructivist theory, a proponent would likely provide learners with an environment that includes access to written texts, team learning opportunities, and demonstrations or simulations to facilitate the development of the skills to be acquired. Finally, the location, frequency, and duration of training would be critical considerations for the efficacy of the instruction. Training based on constructivist theory would likely take place in an environment in which learners can interact with peers and have hands-on experience with actual equipment or simulations of a system of interest, rather than in a classroom setting. With so many parameters, the number of potential instructional strategies employed to train an operator is nearly limitless. A variety of these instructional strate-

gies are under investigation in the studies being conducted to develop IMPRINT algorithms for the ITAE program.

IMPRINT Training Algorithm Development for Operators

Background

A tool that provides insights into the relative effectiveness of various training strategies for operators of a given system could be highly valuable to the training developer seeking to optimize human-system performance. The goal of this study is to begin to quantify the effects of various instructional strategies on operator performance and to subsequently create training effect algorithms that can be implemented within an IMPRINT environment. Such a capability would give the IMPRINT modeler the ability to predict how changes in instructional strategies might impact the time and accuracy of tasks being modeled.

As a first step in scoping the issue, we considered a dimension of instructional design that is at the heart of many cost-benefit trade-offs. This dimension is the level of *instructor-student interaction.* In our schools, low student-teacher ratios are thought to be desirable as they allow for more student-teacher interaction. However, these low ratios are also associated with higher costs in terms of more classrooms and more teachers. Another training approach used with increasing frequency is computer-based training (CBT), which minimizes instructional costs while essentially eliminating any instructor-student interaction. There is clearly a financial cost associated with increased instructor-student interaction. Our goal is to quantify the benefit (if any) of such interaction to performance.

Quantifying effectiveness of the training strategies for given task types also poses a challenge, as the term "effectiveness" can involve a number of different parameters with regard to training. For example, one could consider the strategy that leads to the fastest acquisition of requisite skills as being the most effective. Another view is that effectiveness is judged by the level of performance that can ultimately be achieved with a given instructional strategy. Yet another view might suggest that the instructional strategy that leads to the highest skill retention rate over time is the most effective strategy. In most cases, all three are of interest to a training system developer. For the purposes of this study, we are interested in effectiveness with regard to both skill acquisition and decay as measured by operator task time and accuracy.

Method

This study employs a 3x2x5 mixed design. The treatments are three training strategies (minimally, moderately, and highly instructor interactive), two retention intervals (30 and 60 days) and five tasks. Table 1 characterizes the three training strategies employed.

Sixty (60) college students are participating in the study, with twenty (20) being randomly assigned to each training strategy group. Within each training strategy group, half of the students were assigned to a thirty (30) day retention condition and half to a sixty (60) day retention condition.

Upon entering the study, students receive training on a series of five Unmanned Aerial System (UAS) tasks. The form of this training varies across groups, as shown in Table 1. The goal of the training, which focuses primarily on sensor operator duties, is to enable the participants to perform these UAS tasks proficiently on a desktop UAS simulator. After completing the academic portion of the training, participants perform a series of practice trials for each of the

five UAS tasks until they reach a level of proficiency. For each practice trial, task time and accuracy data are recorded. After thirty (30) or (60) days, depending on the retention condition to which they are assigned, participants return and perform additional simulator-based trials for each UAS task and time/accuracy data are again recorded.

Table 1: Three Levels of Instructor-Student Interaction as Implemented in the Study

	Academic Phase	Simulator Practice Phase
Minimally Interactive Condition	CBT with part-task exercises	Instructor available to answer only system operation questions
Moderately Interactive Condition	Classroom lecture with part-task exercises	Instructor available to provide task advice if asked
Highly Interactive Condition	Classroom lecture with part-task exercises, memory probes, and checks for understanding	Instructor monitors performance and provides trial-to-trial task advice and coaching

The data resulting from this design will allow ITAE researchers to examine the shape of learning curves for given task types and how these curves might vary as a function of instructor-student interaction. Further, researchers will be able to compare the degree to which instructor-student interaction during training may impact the rate at which skills decay over a period of non-use. Once these data are converted to algorithms and implemented in an IMPRINT environment, we will have achieved a first-step in providing training system designers a modeling tool to aid in training system design decisions.

IMPRINT Training Algorithm Development for Teams

Background

A recent review of the team performance and team training literature (Crabtree, Doyal, & Salas, 2008) indicated that considerable research has been conducted to identify: the characteristics of effective teams, the necessary teamwork skills, the required training strategies, and the assessment of the effectiveness of those training strategies. Team training theorists have developed a large number of team performance and team training conceptual models to serve as frameworks on which to build training concepts and approaches. Recent studies emphasize the importance of distinguishing between task-related skills and teamwork skills, and understanding team processes and their contribution to team performance. Unfortunately, because of the enormous diversity of the conceptual models and a lack of validated guidelines, there is little standardization across resulting training concepts, especially with regard to content, delivery, and assessment of both processes and outcomes (van Berlo, Lowyck, & Schaafstal, 2007). Thus, the results of team training interventions can rarely be compared, and the task of determining a "mean" effect of a given strategy is practically impossible. Furthermore, a meta-analysis of more than 1200 team studies revealed that only nine provided sufficient data to enable researchers to conclude that three team training strategies actually affect teamwork outcomes. These strategies are *team coordination training (TCT)*, *team cross training (CT)*, and *team guided self-correction training (GSC)*.

The ITAE Program's investigation into team training strategy effects will develop the capability within IMPRINT to represent the effects of team training interventions on team performance. Accordingly, the relative effects of each training strategy on team task completion time and team task accuracy will be quantified. Furthermore, to understand the relative impact of each training strategy on the team processes that influence performance, ITAE Program researchers are designing an empirical study to evaluate three training strategies (*TCT, CT, and GSC*) in a military-relevant team environment. The study will take place within the context of Unmanned Aerial System operators performing a close air support (CAS) mission. The approach used in the design of this study is based on the teamwork and team training model summarized in Figure 1.

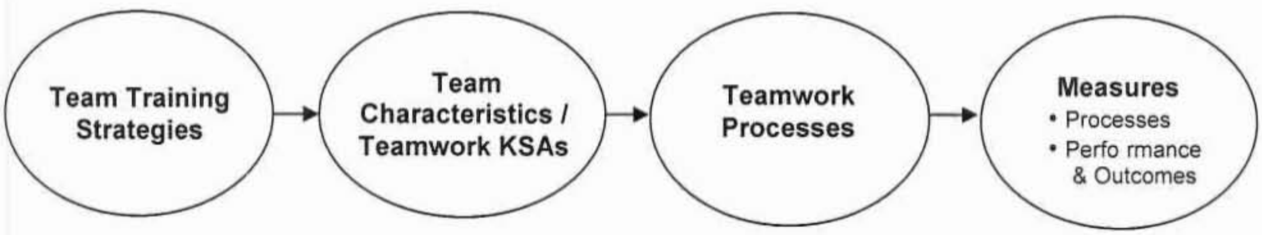

Figure 1. High-level illustration of teamwork and team training model used in study

Figure 1 suggests that team training strategies affect team characteristics, specifically teamwork knowledge, skills, and attitudes (KSAs). The changes in team KSAs, observable in team processes, can be measured and recorded. Changes in team processes affect team effectiveness, which can be recorded objectively in time and accuracy measures.

Method

Because some studies have failed to support the straightforward relationship between team processes and outcome measures suggested by this model, the current study will control the variables that may have influenced earlier results. As this project is still in the planning stage, many details of the experimental design, apparatus, and procedures have yet to be developed. However, the high-level experimental design and the metrics we intend to examine will be discussed.

A between groups design will be used to examine the effects of a single independent variable (team training strategy) that will have four levels: (1) no team training (control condition); (2) team coordination training; (3) cross-training; and (4) guided self-correction.

Twenty four three-member teams will be formed and randomly assigned to one of the four conditions. These teams will be trained as UAS operators in the positions of pilot, sensor operator, and mission coordinator. Initial training will be limited to the individual position skills necessary to support the close air support (CAS) role. Following this individual position training, three groups will receive teamwork training, and the control group will receive none.

Upon completion of training, the teams will perform a series of simulated UAS CAS missions. Due to the nature of the task and the information available to the individual team members, the CAS task is highly teamwork-interdependent, and should be fertile ground for observing and recording team processes. Because the mission has time and accuracy constraints, objective outcome measures are available and will be recorded.

Results of this effort should allow researchers to identify the relationships among team training strategy, resulting team processes, and resulting team performance. Such data will provide a first step in identifying both algorithms that could be incorporated in IMPRINT to predict team

performance moderators as a function of team training strategy, and also help provide guidance to IMPRINT modelers on how to best design team task network models to reflect team process differences as a function of team training strategy.

IMPRINT Training Algorithm Development for Maintainers

Background

Air Force training for maintenance technicians typically includes classroom instruction on the characteristics of a system, which may be instructor-led or computer-based. Students receive instruction on the system's theory of operation and the instructor usually demonstrates maintenance procedures. In some cases, individuals or groups of students are provided the opportunity to conduct hands-on practice on the actual weapon system, a simulator, or a part-task trainer.

Because task practice is sometimes absent during training, instruction with and without hands-on practice will be investigated in the maintenance training study described in this paper. Examining these instructional approaches for maintenance will enable IMPRINT modelers to predict the effect they will have on maintenance technician performance and how to best allocate resources.

It is anticipated that this study will provide significant insight into the effect of instruction on maintainer performance by assessing the four principles applied to task-centered learning described by Merrill (2001, 2002, 2002a, 2007). The four principles are: presentation, recall, demonstration and application. Merrill (in press) describes application of these principles, as illustrated in Table 2.

Table 2. Task Centered-Instructional Strategies[1]

	INFORMATION		PORTRAYAL	
	"Tell " Information **PRESENTATION**	*"Ask"* Remember Information **RECALL**	*"Show"* Portrayal **DEMONSTRATION**	*"Do"* Apply info to portrayal **APPLICATION**
Kinds-of	Tell the definition.	Recall the definition.	Show several specific examples	Classify new examples.
How to	Tells the steps and their sequence.	Recall the steps and their sequence.	Show the procedure in several different situations.	Carry out the procedure in new situations.
What happens	Tell the conditions and consequence involved in the process.	Recall the conditions and consequence involved in the process.	Show the process in several different situations.	Predict a consequence or find faulted conditions in new situations.

The instruction received by subjects in the maintenance study consists of varying the combination of the *instructional tactics* "tell," "ask," "show," and "do." The instructional strategy that mirrors the Air Force instructional approach, Instruction with Practice, includes the tactics "tell," "ask," "show," and "do" (abbreviated as TASD). The instructional strategy that represents the

[1] From Merrill, (in press).

alternative Air Force instructional approach, Instruction without Practice, includes the tactics "tell," "ask," and "show" (abbreviated as TAS).

Method

Maintainers perform a variety of unique job functions, including electrical checks on automatic transmission components and wheel balancing. The following five maintenance tasks were selected for the study from these task categories: (1) measure solenoid resistance, (2) determine if solenoid is faulty, (3) remove wheel weights, (4) determine wheel weights required, and (5) install wheel weights. The performance standard for all tasks is accuracy. Time was measured to determine how close to expert performance the participants come during practice and the trials.

Fifty students participated for each instructional strategy. The "tell" and "ask" components of the instruction were identical for all participants. In the TASD condition, participants were provided a one trial practice session. A different demonstration of the task was provided to the remaining participants. To assess the extent of performance decay, participants returned for reassessment 60 days following initial training and testing.

A performance checklist was provided to participants and researchers to accurately record the errors made. Task elements performed correctly and ability to meet time standards was also recorded. During the practice session of the TASD strategy, participants were permitted to ask questions and receive feedback on each specific item in the checklist during the practice session. During the testing phase of the study, participants were provided feedback on their performance.

Conclusion

With the completion of these research efforts, IMPRINT users will have a tool that better estimates how training can impact system performance and mission success. Designing training to better support systems as well as human performance can reduce overall ownership costs. Enhancement of the IMPRINT training algorithms will further support making trade-off assessments between acquisition and training costs, adding features that would reduce subsequent training versus deleting those features and incurring subsequent training penalties. Prior to the commencement of the IMPRINT training algorithm enhancement work, such tradeoffs have received little detailed, explicit treatment during design evaluations. The current efforts will enhance this capability. In cases where knowledge and skill demands require the maintenance of proficiency, the training implications required to achieve desired levels of mission success can be estimated, making it easier to plan for and justify operational unit training funds for expenditures that assure adequate combat performance levels in personnel sent into theatre. With that kind of modeling capability, the training community in the operating commands can be better supported. That can save lives as well as assure combat success.

References

Crabtree, M.S., Doyal, J.A., & Salas, E. (2008). *ITAE Team Training Literature Review.* Internal report prepared in partial fulfillment of Contract FA8650-06-C-6651 with Air Force Research Laboratory Warfighter Readiness Research Division, 6030 South Kent Street, Mesa, AZ 85212-6061. Prepared by: Science Applications International Corporation, 4031 Colonel

Glenn Highway, Beavercreek, OH 45431-1673.
McDermott, P.L., Clamann, M. P., Quesada, S. K., Hutchins, S. D., Archer, R. D., Peters, S. D. & Voeller, C. K. (2007). Improved Performance Research Integration Tool (IMPRINT) Training Data. United States Air Force Research Laboratory Final Report, AFRL-HE-AZ-TR-2007-0028.
Merrill, M. D. (2001). Components of Instruction: Toward a Theoretical Tool for Instructional Design. *Instructional Science*, 29, 291-310.
Merrill, M. D. (2002). First principles of instruction. *Educational Technology Research and Development*, 50(3), 43-59.
Merrill, M. D. (2002a). A Pebble-in-the-Pond Model for Instructional Design. *Performance Improvement*, 41(7), 39-44.
Merrill, M. D. (2007). First principles of instruction: a synthesis. In R. A. Reiser & J. V. Dempsey (Eds.), *Trends and Issues in Instructional Design and Technology*, 2nd Edition (Vol. 2, pp. 62-71). Upper Saddle River, NJ: Merrill/Prentice Hall.
Merrill, M. D. (in press). First Principles of Instruction. Instructional Design In C. M. Reigeluth and A. Carr (Eds.). *Instructional Design Theories and Models III*. Lawrence Erlbaum Associates Publishers.
Salas, E., Klein, C., & DiazGranados, D. (2007). *What do we know about developing teams? The Results of Recent Quantitative Reviews of Team Building and Team Training.* A paper prepared by Department of Psychology & Institute for Simulation and Training, University of Central Florida, 3100 Technology Parkway, Suite 132, Orlando, FL 32826.
van Berlo, M.P.W., Lowyck, J., & Schaafstal, A. (2007). Supporting the instructional design process for team training. *Computers in Human Behavior*, 23, 1145–1161.

Biographies

Patricia C. Fitzgerald is a Research Psychologist with the Warfighter Readiness Research Division in the Human Effectiveness Directorate of the Air Force Research Laboratory. In addition to conducting a variety of training research studies, she is the Program Manager for the Improved Performance Research Integration Tool (IMPRINT) Training Algorithm Enhancement program. She served as an Information Systems Specialist for 20 years before beginning her career with the Air Force. Ms. Fitzgerald holds a Master of Science degree in Aviation Human Factors and a Bachelor of Arts degree in Psychology.

Dr. Dee H. Andrews is the Division Senior Scientist (ST) with the Warfighter Readiness Research Division in the Human Effectiveness Directorate of the Air Force Research Laboratory (AFRL). As a Senior Scientist (ST), Dr. Andrews is the AFRL's principal scientific authority for training research. Dr. Andrews' responsibilities include sustaining technological superiority for training by planning and conducting theoretical and experimental studies. He also is responsible for mentoring and developing dedicated technical staff to assure quality in training research, and he represents AFRL in training research matters to the external scientific and technical community.

Jeff Doyal is a research psychologist at SAIC and is the program manager for SAIC's ITAE efforts. He has led and supported numerous human factors research and human performance modeling efforts for the Air Force Research Laboratory for the past seventeen years. He holds

an undergraduate degree in psychology and a masters degree in applied behavioral science. He is a member of HFES and holds a Project Management Professional (PMP) certification.

William J. Walsh has been designing innovative training and education technologies for military and civilian customers since 1968. His work has ranged from defining requirements for new training systems, designing and developing e-learning and intelligent tutors, and developing and delivering train-the-trainer courses. Mr. Walsh has been active contributor to the research community as an author and presenter. Mr. Walsh has a BA from the University of Scranton and a MA from The Pennsylvania State University. He is a member of NTSA.

Mark Crabtree is a human factors engineer with SAIC, and serves as the technical lead for the ITAE study on team training effects. As a former employee of SRL, Logicon, and Northrop-Grumman, he has supported cognitive performance research in AFRL/HE for over 30 years. Mark holds an undergraduate degree in psychology and has completed extensive graduate coursework in human factors engineering and computer systems analysis. He has authored or co-authored over 70 publications covering numerous aspects of human performance. He is a member of the HFES and the SAE.

Doug Meador is a human factors engineer at SAIC and is the lead experimenter on the ITAE individual program. Doug is a former United States Air Force navigator and has worked in a variety of human factors engineering environments such as helmet-mounted display (HMD) symbology design, workload analysis and situation awareness assessment. His undergraduate degree is in aeronautics and he holds a masters degree in human factors engineering. He is a member of AIAA.